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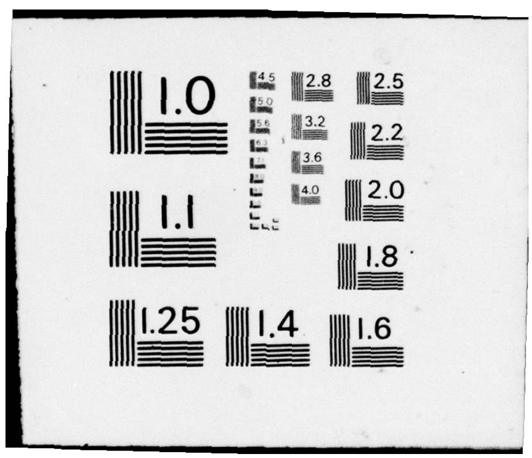
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ROCKET-BORNE IR SENSOR DEPLOYMENT SYSTEM

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31 March 1976

Scientific Report No. 3

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

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19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 AFGL-TR-76-0125 — 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER: 9
4. TITLE (and Subtitle): 6 ROCKET-BORNE IR SENSOR DEPLOYMENT SYSTEM.	5. TYPE OF REPORT & PERIOD COVERED: Scientific - Final Rept.
	6. PERFORMING ORG. REPORT NUMBER: Scientific Report No. 3
7. AUTHOR(s): 10 Thomas J. Campbell	8. CONTRACT OR GRANT NUMBER(s): 15 F19628-73-C-0232
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Wentworth Institute, 550 Huntington Avenue, Boston, Massachusetts 02115	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62101F, 76590401
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731, Contract Monitor: C. Nealon Stark, LCR	12. REPORT DATE: 11 31 Mar[redacted] [redacted]76
	13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14 Scientific-3 — 12 25p.	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

16 7659 17 04

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

IR sensor Deployment System
Open loop control system
Cap removal mechanism
Failsafe Operation
Data Collection Points
Logic Control Unit
Gimbal mounted sensor
ACS
Payload Programmer
Sensor Deployment Program
Failsafe Program

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A control system was designed and developed to deploy, position, and stow a rocket-borne IR telescope.

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CONTENTS

ILLUSTRATIONS

ROCKET-BORNE IR SENSOR DEPLOYMENT SYSTEM

INTRODUCTION

In 1970, Wentworth Institute fabricated and assembled the first of a series of basically similar sounding rocket payloads designated by the Air Force Cambridge Research Laboratories (now the Air Force Geophysics Laboratory) as the Hi-Star Project. One phase of this task was the design and development of a control system suitable for the deployment of a cryogenically-cooled, infra-red sensing instrument. The resulting system, the subject of this report, was used on seven payloads (Nos. A04.004-2, -4, -5, -6, -7, -8 and -9) and, with minor modifications, on three more (Nos. A05.391-1, -2 and -3). The system was flown again, though with greater modification, in the Fall of 1975 on the Super Hi-Star payload.

CONTROL SYSTEM REQUIREMENTS

The requirements which had been established for this control system are set forth in this Section.

Sensor Deployment Program

The system's most vital requirement is that it must properly position or deploy the sensor when the sounding rocket reaches a predetermined altitude. First of all, blow-off doors are jettisoned from the nose cone; this removes any structure that might obstruct the sensor's movements or field of view. Then, referring to Figure 1, the following sequence of events is initiated by the Attitude Control System (ACS) or payload programmer.

Step 1: The sensor's protective cap is removed.

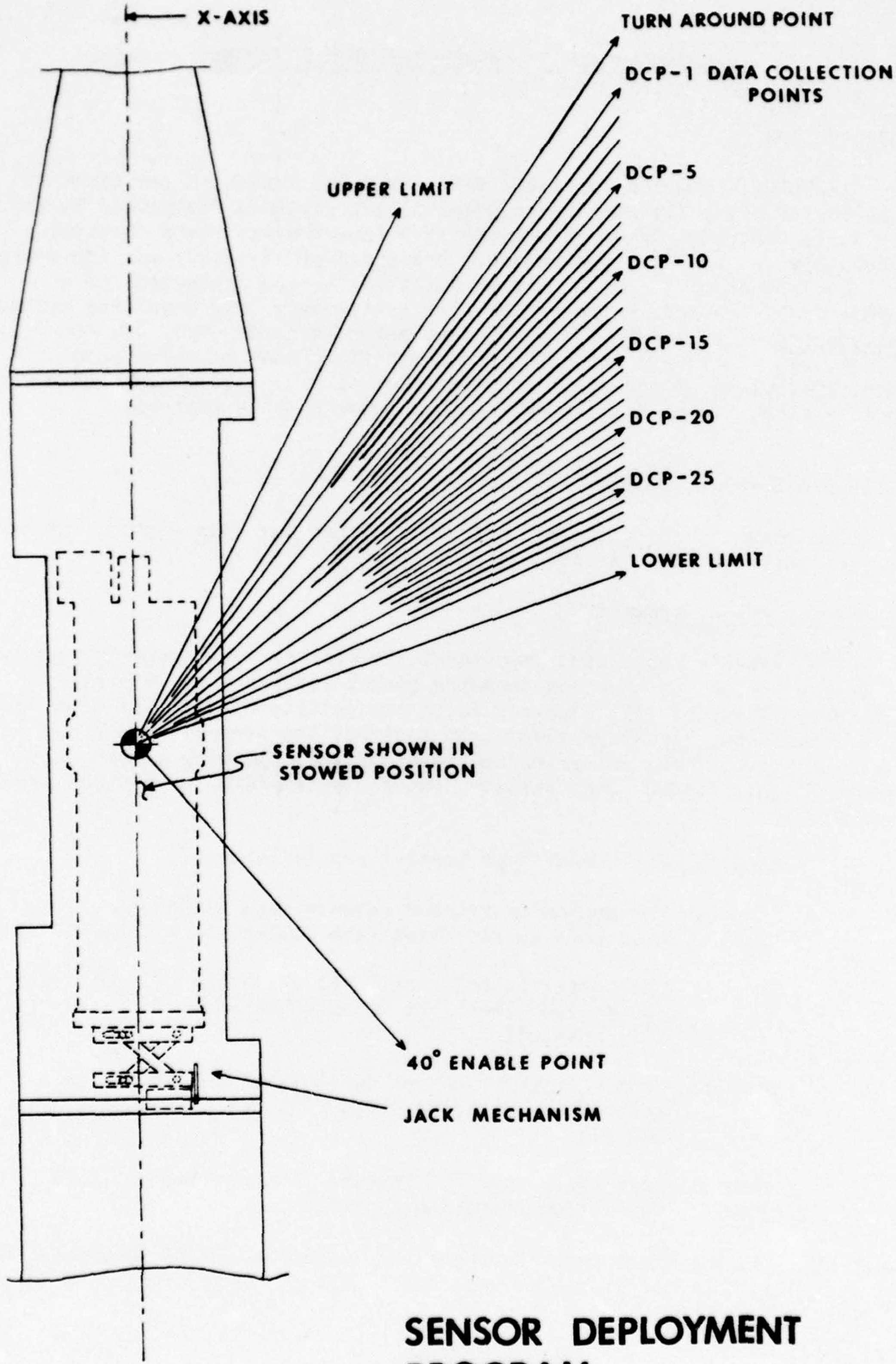
Step 2: The sensor is rotated outward from within the nose cone to its first Data Collection Point (DCP #1).

Step 3: The sensor is held at DCP #1 while the ACS rotates the payload about its longitudinal axis for one full revolution.

Step 4: Upon completion of one revolution, the sensor is rotated inward to be stopped at the next point, DCP #2.

Step 5: Once again, the ACS revolves the payload one full revolution about its X-axis.

It is during these periods of payload revolution, with the sensor held at its DCPs, that the infra-red data is collected. This process of stepping



SENSOR DEPLOYMENT PROGRAM

Figure 1.

the sensor to the next DCP and revolving the payload is repeated until it is time to "button it up" for reentry. Then, the sensor is rotated inward to the Stow position and its cap is replaced, thus completing the last step of the deployment program, thereby readying the sensor for the rigors of reentry and subsequent recovery.

DCP Positions

The position of DCP #1 relative to the payload's longitudinal axis varies from payload to payload; it is dependent upon the specific mission's requirements. The control system must accommodate these changes.

DCP Spacing

The angular spacing between each DCP depends upon the sensor's field of view. For this series of payloads, the spacing was $1.1^\circ \pm 0.05^\circ$.

Sounding Rocket Environment

The sensor's deployment system must operate satisfactorily in an environment common to sounding rockets.

Vibration: Test Level

a. 0.003 G^2Hz. at 20 Hz. + 12 db/octave from 20 Hz. to 100 Hz.
b. 0.028 G^2Hz. from 100 Hz. to 1000 Hz.
c. -6 db/octave from 1000 Hz. to 2000 Hz.

Shock: Test Level

100 G peak, 6 millisecond sawtooth.

Payload B+: Test Level

+ 28 VDC $\pm$ 4 VDC.

Longitudinal Acceleration: Flight Condition

20 G peak.

Spin Rate: Flight Condition

5 rps

Flight Time:

10 minutes.

PHYSICAL DESCRIPTION

A general explanation of the payload and the mechanism of its deployment system is in order before discussing the essentials of the control system.

Main Casting

Figure 2 shows the casting that forms the basic chassis of the sensor deployment system. It is extremely rigid in order to maintain the alignment of the IR sensor with the rest of the payload. The sensor is housed within the chassis as shown in Figure 3. The inner surface of this casting is smooth and glossy, and is finished in a white baked epoxy paint; this aids in maintaining the cleanliness required within this portion of the payload. Two large ports, covered by blow-off doors during the early portion of the flight, provide clearance when the sensor rotates outward to collect data. (See Figure 4).

Sensor Mounting Ring

The IR sensor mounts in a ring that is gimballed about one axis. This axis is at a right angle to, and passes through, the payload's longitudinal axis. The gimbal shaft protrudes through, and is supported by, opposite walls of the casting. One end of this shaft is connected to the gimbal's drive assembly, and the other to its brake assembly. Figures 3 and 4 show the two bulbous skin fairings used to cover these two assemblies.

Gimbal Drive Assembly

Gear Box -- The Gimbal Drive Assembly consists of a gear box (see Figure 2) which couples a 25 VDC planetary geared drive motor and an optical shaft encoder to one end of the gimbal's shaft. A 7.5:1 reduction ratio worm drive, combined with the 639.9:1 reduction of the planetary gear motor, gives a rate of sensor deployment of 16^o per second on Hi-Power and 8^o per second on Low Power.

Shaft Encoder -- The optical shaft encoder is coupled to the gimbal's shaft by a set of anti-backlash gears which gears it up 2.54:1. This gear ratio, combined with the 2^{13} bit resolution of the shaft encoder, gives approximately 0.0173^o of shaft rotation per increment of encoder output. This output is used by the control system's logic; it is also an in-flight monitor through telemetry of the sensor's deployment angle.

Function Cam -- This unit is also a part of the Gimbal Drive Assembly (see Figure 5). It can be seen only when the gear box is removed. This cam, mounted directly to the gimbal shaft, is used to actuate the 40^o Enable Switch, Sw 4, and the Upper Limit Switch, Sw 6. The cam has built-in provisions for making small amounts of angular adjustment needed to accommodate slight differences between payloads.

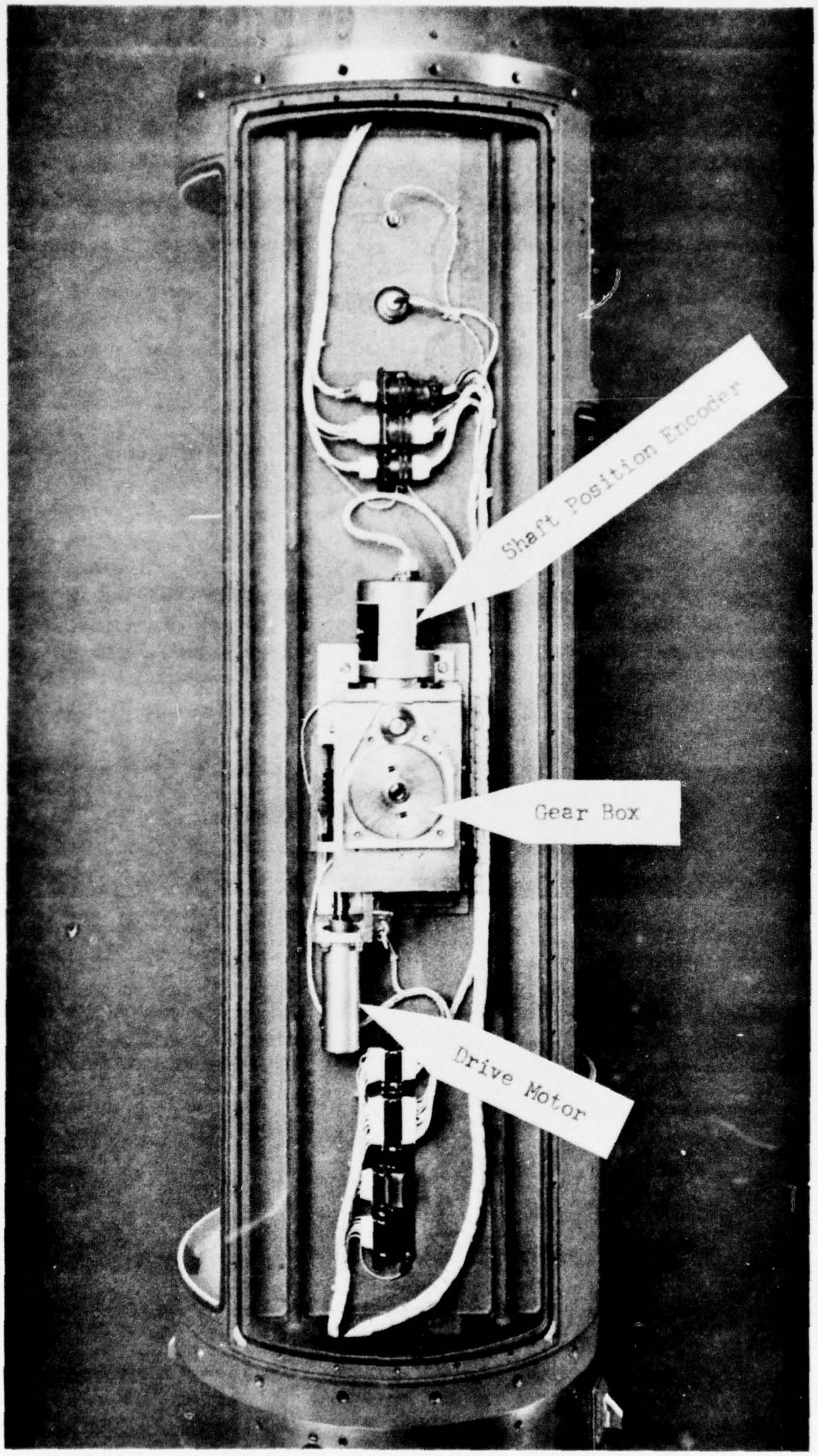


Figure 2. Main Casting showing the Gimbal Drive Assembly

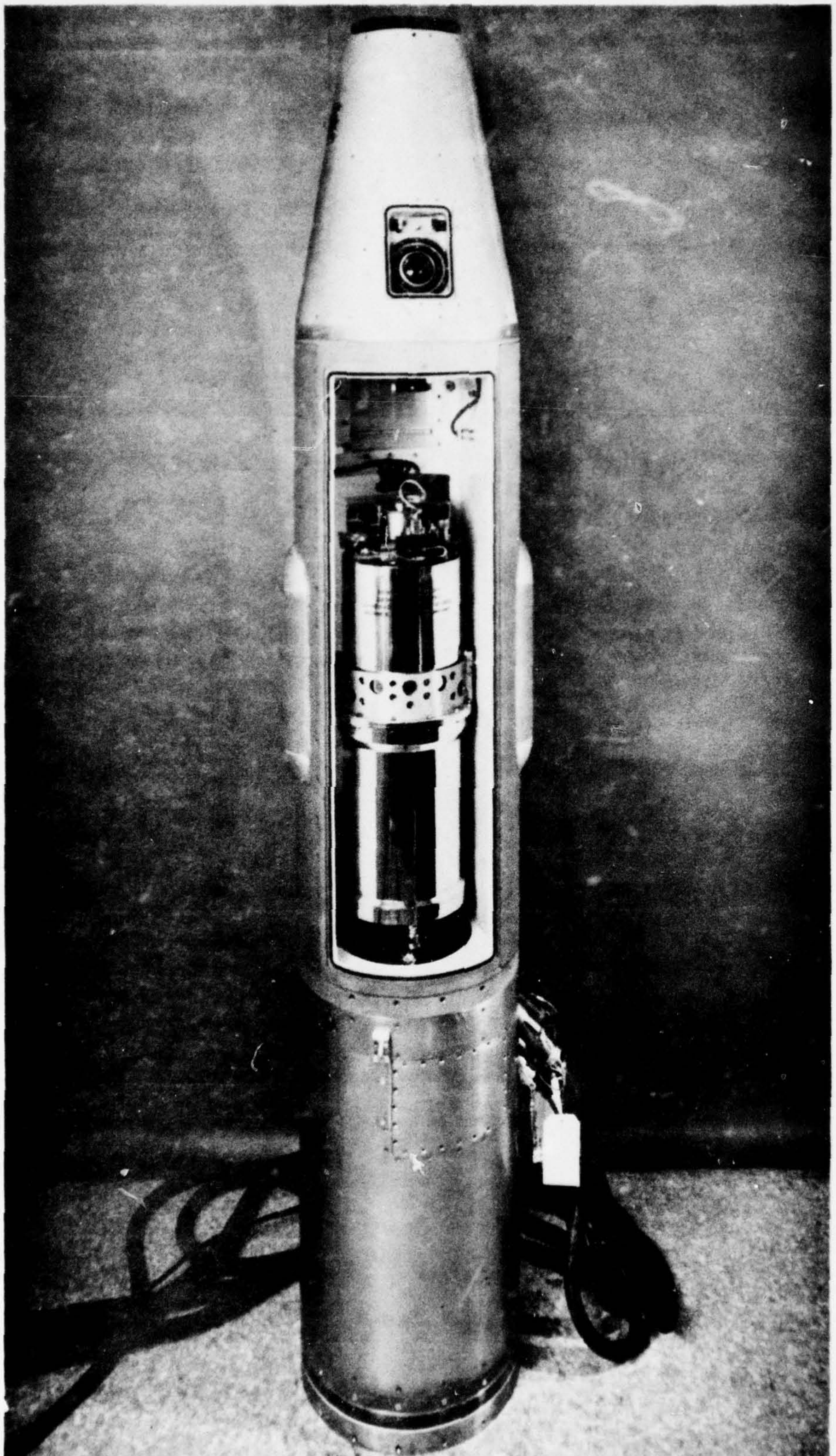


Figure 3. Payload with Sensor in "Stow" Position

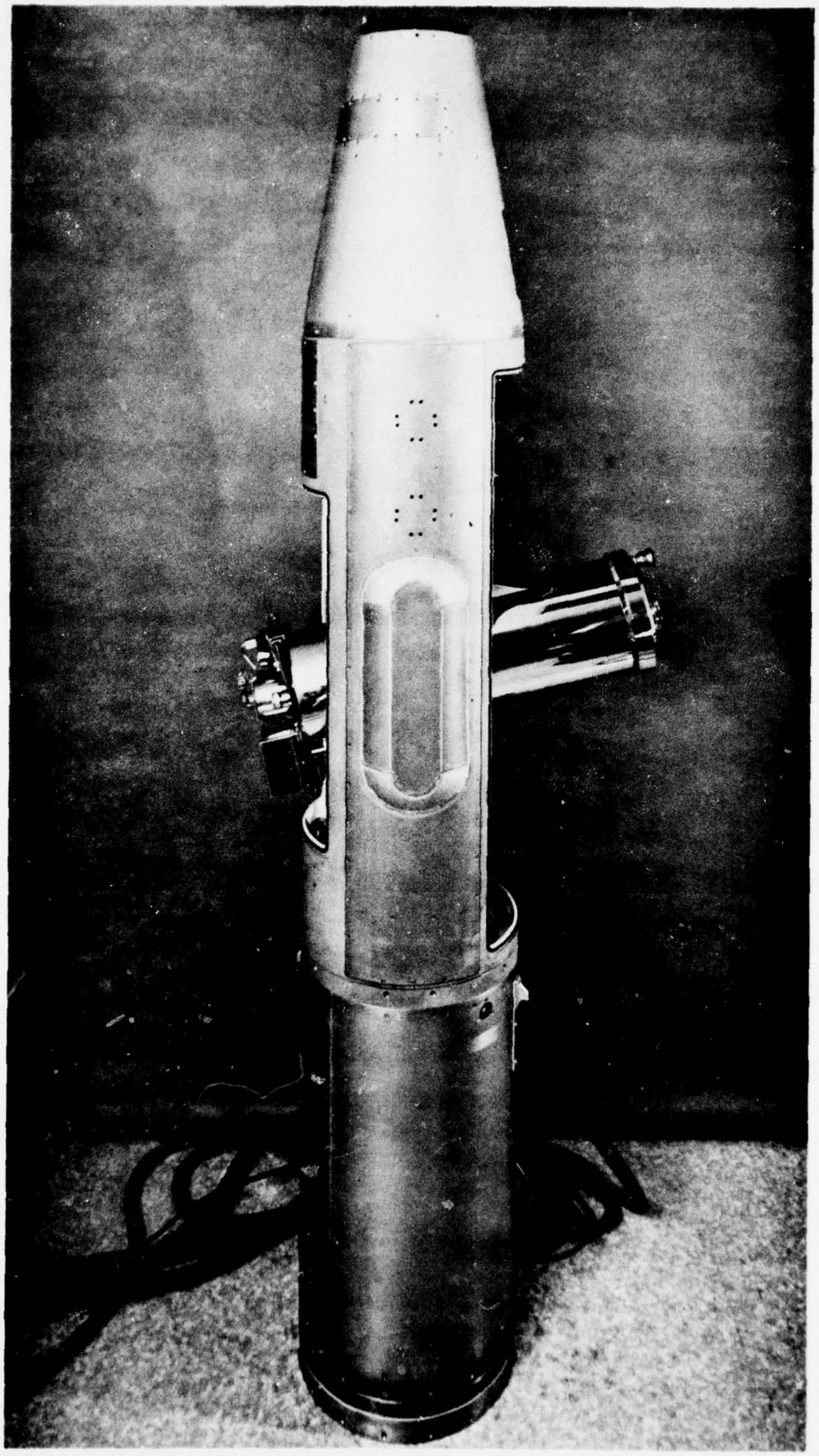


Figure 4. Payload with Sensor deployed

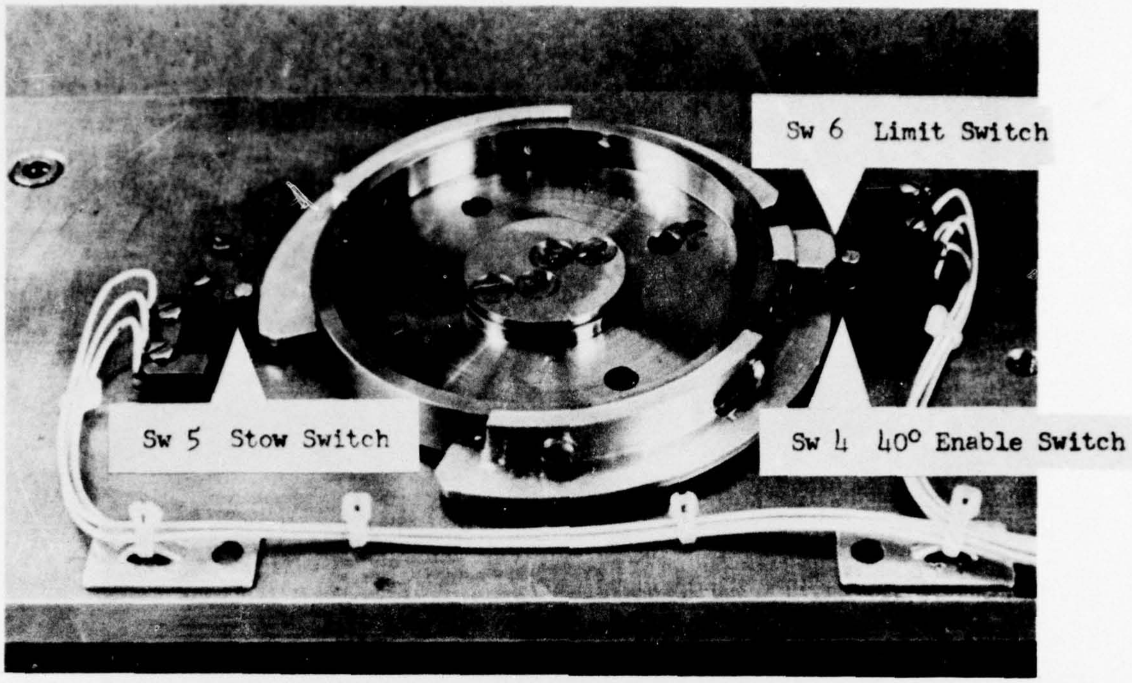


Figure 5. Function Cam

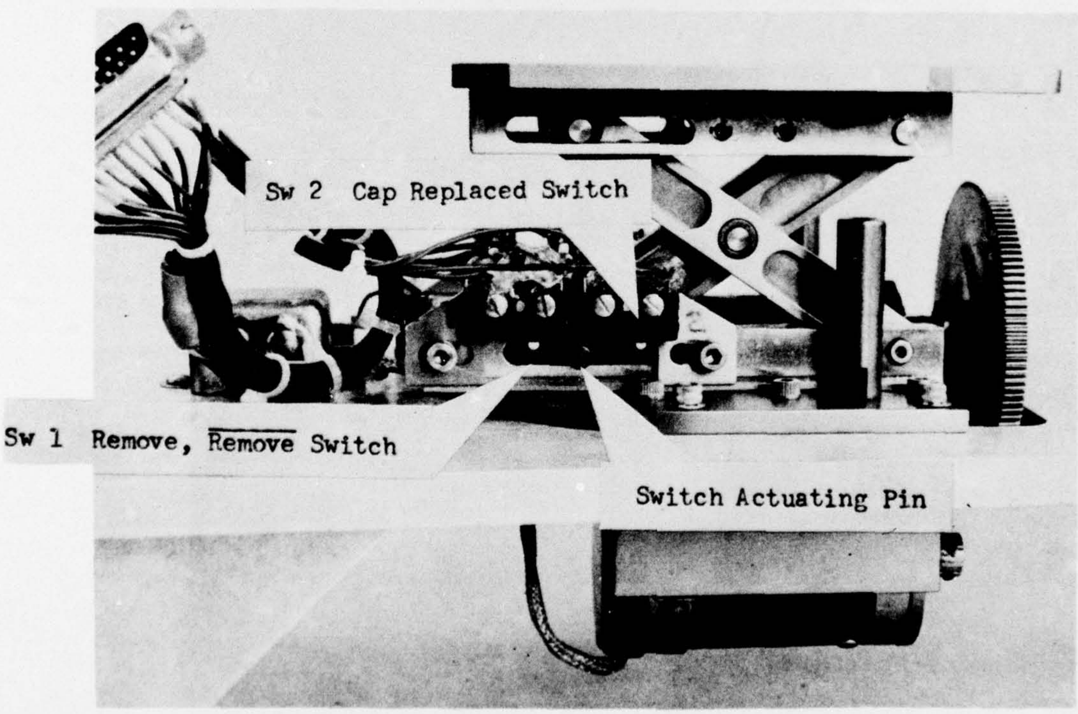


Figure 6. Jack Mechanism

Gimbal Brake Assembly

Electromagnetic Brake -- The other end of the gimbal shaft is coupled to an electromagnetic brake. It aids the dynamic braking of the IR sensor's movement and it locks it into place at each DCP. This brake consists of two parts: a stationary field coil mounted to the casting, and an armature mounted directly to the gimbal shaft. When electrical power is applied to the field, it magnetically attracts the armature, thus forcing the braking surfaces together.

Precision Pot -- Mounted also to the Gimbal Brake Assembly is a multi-turn precision pot. It is driven through anti-backlash gears by the gimbal shaft and provides an analog output signal used to quickly check gimbal shaft rotation during sensor deployment.

Jack Mechanism

The IR sensor has a protective cap that is removed when collecting data and is replaced afterward. The mechanism shown in Figure 6 is used for this purpose. The cap is bolted to the jack's platform so that when the jack is lowered, the cap is removed and vice versa. The mechanism is sufficiently sturdy so that, when it replaces the cap, it locks the sensor in the stowed position.

Three switches are mounted on this device. Sw 3 is a limit switch. It turns off the motor if the jack is run to its mechanical limit, preventing self destruction. The other two switches are used to integrate the jack's operation with other functions. Figure 1 shows approximately where this jack is mounted in the payload.

Logic Electronics Package

This package is the heart of the control system. Figures 7a and 7b show the package with and without its cover. It contains four circuit boards which employ both printed circuit and wire wrap fabrication techniques. It is mounted with the power control relays and supplemental circuitry in the payload section just aft of the casting. This section is reserved for the payload's support electronics.

CONTROL SYSTEM OPERATION

The control system which has been developed to meet the system requirements can be considered a semi-closed loop system. The normal operational mode is open loop. No sensor positional data is used to adjust the sensor's position each time it is stopped at a DCP. However, a closed loop arrangement is employed to overcome certain types of system failure. A description of these two operational modes follows.

Normal Operation

Figure 8 (Control System Block Diagram) illustrates the interaction between the various elements of the control system.

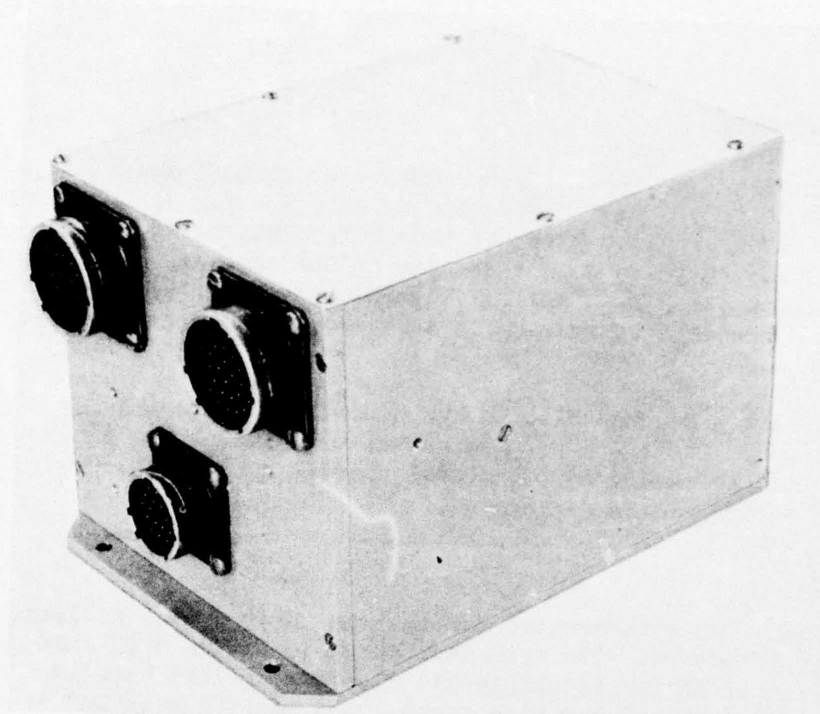


Figure 7a. Logic Control Unit

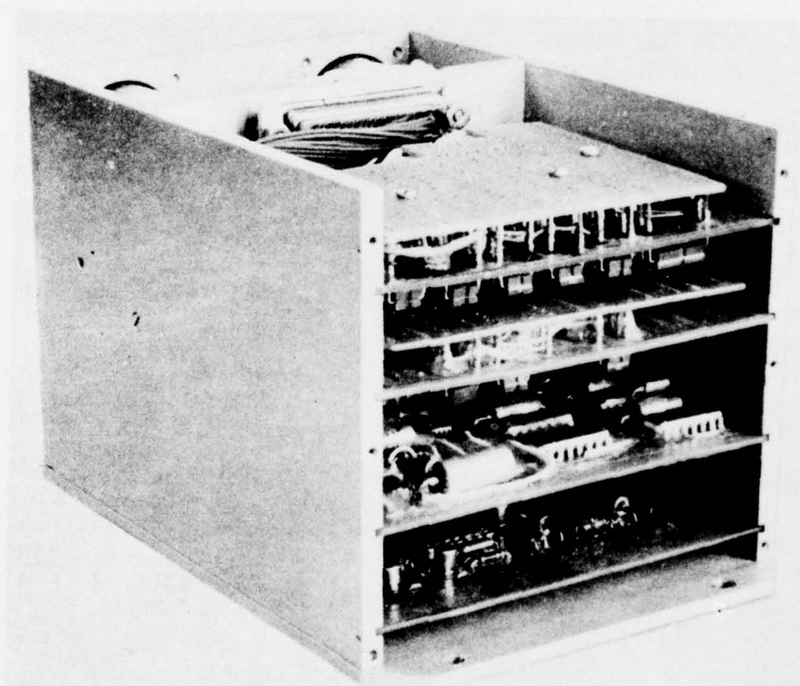


Figure 7b. LCU with Cover removed

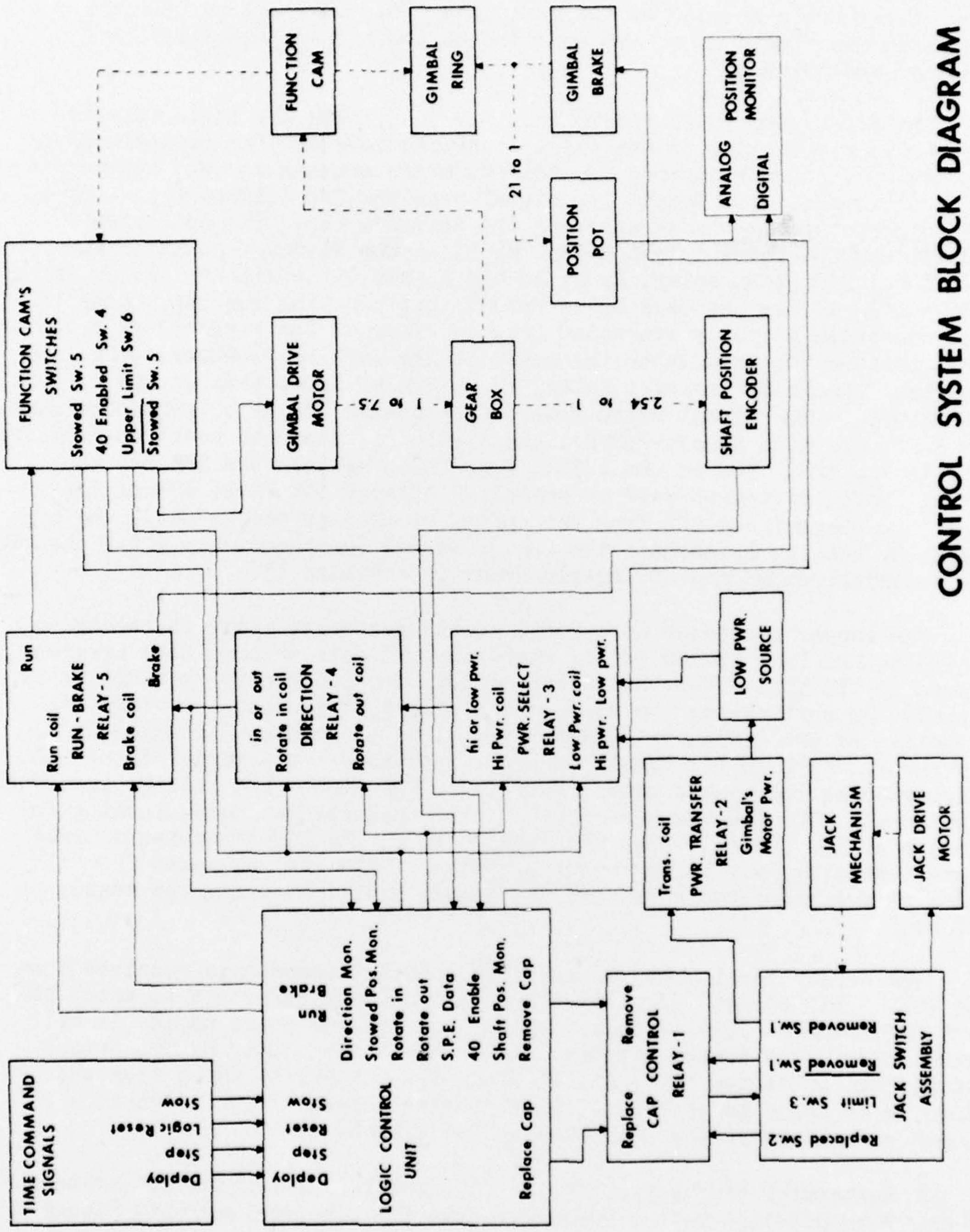

CONTROL SYSTEM BLOCK DIAGRAM
TIME COMMAND SIGNALS
Deploy
Step
Logic Reset
Stow
LOGIC CONTROL UNIT
Deploy
Step
Reset
Stow
Replace Cap
Run
Brake
Direction Mon.
Stowed Pos. Mon.
Rotate in
Rotate out
S.P.E. Data
40 Enable
Shaft Pos. Mon.
Remove Cap
Replace
Remove
CAP CONTROL
RELAY-1
Replaced Sw.2
Limit Sw.3
Removed Sw.1
Removed Sw.1
JACK SWITCH
ASSEMBLY
JACK
MECHANISM
JACK DRIVE
MOTOR
Trans. coil
PWR. TRANSFER
RELAY-2
Gimbal's
Motor Pwr.
LOW PWR.
SOURCE
hi or low pwr.
Hi Pwr. coil
PWR. SELECT
RELAY-3
Low Pwr. coil
Hi pwr.
Low pwr.
in or out
Rotate in coil
DIRECTION
RELAY-4
Rotate out coil
Run
Run coil
RUN-BRAKE
RELAY-5
Brake coil
Brake
FUNCTION CAM'S
SWITCHES
Stowed Sw.5
40 Enabled Sw.4
Upper Limit Sw.6
Stowed Sw.5
GIMBAL DRIVE
MOTOR
1 to 7.5
GEAR
BOX
1 to 2.54
SHAFT POSITION
ENCODER
FUNCTION
CAM
GIMBAL
RING
GIMBAL
BRAKE
21 to 1
POSITION
POT
ANALOG
DIGITAL
POSITION
MONITOR

Figure 8.

Four commands are used to control the deployment program's sequence of events. They are "Deploy", "Step", "Stow", and "Logic Reset". The first three are generated by the vehicle's ACS. The payload programmer generates the "Logic Reset" in addition to the back-up commands for "Deploy" and "Stow".

The first command is "Logic Reset". It presets the Logic Control Unit (LCU) electronics to the proper starting levels. The second command is "Deploy". Upon receiving it, the LCU sends out Remove Cap, Rotate Out, and Run signals. The Remove Cap signal sets the Cap Control Relay, Ry 1, to the proper position for removing the sensor's cap. The Rotate Out signal sets the Power Select Relay, Ry 3, to the Hi-Power position and the Gimbal Direction Relay, Ry 4, to the Rotate Out position. Power through Ry 1 and Sw 1 runs the Jack Drive Motor, thus removing the cap. When the jack mechanism is fully retracted (cap is clear of the sensor), it actuates SW 1; this switch interrupts the power to the Jack Drive Motor, then energizes the Power Transfer Relay, Ry 2. Power flows through Rys 2, 3, 4, 5 and Sw 5 to the Gimbal Drive Motor. The sensor begins to rotate outward. The Shaft Position Encoder (SPE), see Figure 2, transmits position-indicating data to the LCU. Due to the 2.54:1 gear ratio between the SPE and the Gimbal Shaft, redundant data is generated through the first 40° of deployment. To prevent the LCU from responding to this erroneous data, the 40° Enable Switch, Sw 4, enables the logic control functions only after the sensor has traveled beyond the 40° Enable Point (see Figure 1).

The sensor continues to deploy, rotating outward until it reaches a position, the Turn Around Point, where the SPE data matches data previously stored in the LCU. When this match occurs, the LCU generates a Rotate In signal. By controlling the appropriate relays, this signal reverses the direction of the Gimbal Drive Motor and slows it down by switching it to Low Power. Ry 4 in its Rotate In position also sends a signal to the LCU which enables the brake-control function. The sensor now rotates inward at slow speed. The LCU compares the SPE data with its own data, looking for a match at the DCP #1. When the match occurs, the LCU generates a Brake signal, setting Ry 5 to the brake position. This removes power from the Gimbal Drive Motor and energizes the Gimbal Brake, stopping the sensor at DCP #1.

The sensor remains at DCP #1 until a "Step" command is received from the ACS. This command upgrades the LCU's internal reference to match the next DCP, removes power from the brake, and applies power to the Gimbal Drive Motor. The sensor rotates inward once again until the SPE data matches the LCU's new internal reference for DCP #2, at which time the stopping sequence is repeated. This process repeats itself each time a "Step" command is received throughout the flight.

A successful recovery of the payload requires returning the sensor to its Stow position before reentry. When the LCU receives this "Stow" command, it sends out Run and Rotate In signals. It also disables some of its internal control functions so that the sensor can rotate through any unused DCPs to its Stow position. When it arrives, Stow Position Switch, Sw 5, (see Figure 5), transmits a signal to the LCU. The LCU generates a Replace Cap signal that switches Ry 1. The Jack Drive Motor

starts replacing the cap. The jack does not move very far before Sw 1 is deactuated; at the same time, Ry 2 deenergizes, and power is removed from the gimbal's control relays. As the jack pushes the cap into place, Sw 2 changes the jack motor power to a low level. The jack motor finally stalls, maintaining several pounds of thrust on the sensor cap. This ensures that the cap stays on, and locks the sensor in its Stowed position. The Sensor Deployment Program terminates with this securement of the sensor.

Failsafe Operation

It is possible that a system failure could occur if, for one reason or other, the logic does not recognize a DCP when Ry 4 and Ry 5 are in their respective Run and Rotate In positions. Under these conditions the sensor would be stowed prematurely, thus terminating data collection. This type of failure would happen, for instance, if a certain portion of the SPF data were lost momentarily as the sensor was moving to its next DCP. To prevent this sort of system failure, two failsafe features named Scan Mode and Lower Limit Control have been incorporated in the system design. Referring to Figure 9, Failsafe Program, the following is a description of their operation.

Scan Mode Operation -- Assuming that the system has received a "Step" command, and is now rotating the sensor inward from one DCP to the next, we introduce a glitch (momentary failure) so that the LCU does not recognize when the sensor has reached the next DCP. Instead of stopping, it continues to rotate inward and would stow itself if it were not for the Scan Mode failsafe feature. This feature is designed to generate two error points, Error Point 1, (EP #1), and Error Point 2, (EP #2). Both move each time a "Step" command is received, and, by doing so, maintain their angular relationship with each upcoming DCP. As in our example in Figure 9, the sensor slides past the DCP and reaches EP #1. The LCU recognizes that the sensor has missed its stopping point; consequently, it sends out a Rotate Out signal, thereby reversing the direction of rotation and sending the sensor back toward EP #2. When the sensor reaches EP #2, the LCU sends out a Rotate In signal and the sensor's direction is again reversed. If the effects of the glitch are no longer present, the LCU recognizes this and stops the sensor at the desired DCP. If, by chance, the glitch is still present, the sensor will continue scanning back and forth between the two error points. It will remain in this scan mode until either the glitch disappears and the sensor stops at the desired DCP, or, a "Step" command tells it to move on to the next DCP. Hopefully, the glitch does not affect the following DCPs and the system returns to normal operation.

Lower Limit Control Operation -- This second failsafe feature is provided because of the difficulty in predicting the character of a glitch. EP #1 is closely spaced to the DCP and could be overridden if affected by the same glitch that allowed the system to let the sensor slip past in the first place. Should that happen, once again the sensor would stow itself prematurely. To prevent this occurrence, a fixed position, the Lower Limit Point, provides a second opportunity to turn the sensor around, sending it back to EP #2 and, from there, back to the DCP. It acts like EP #1,

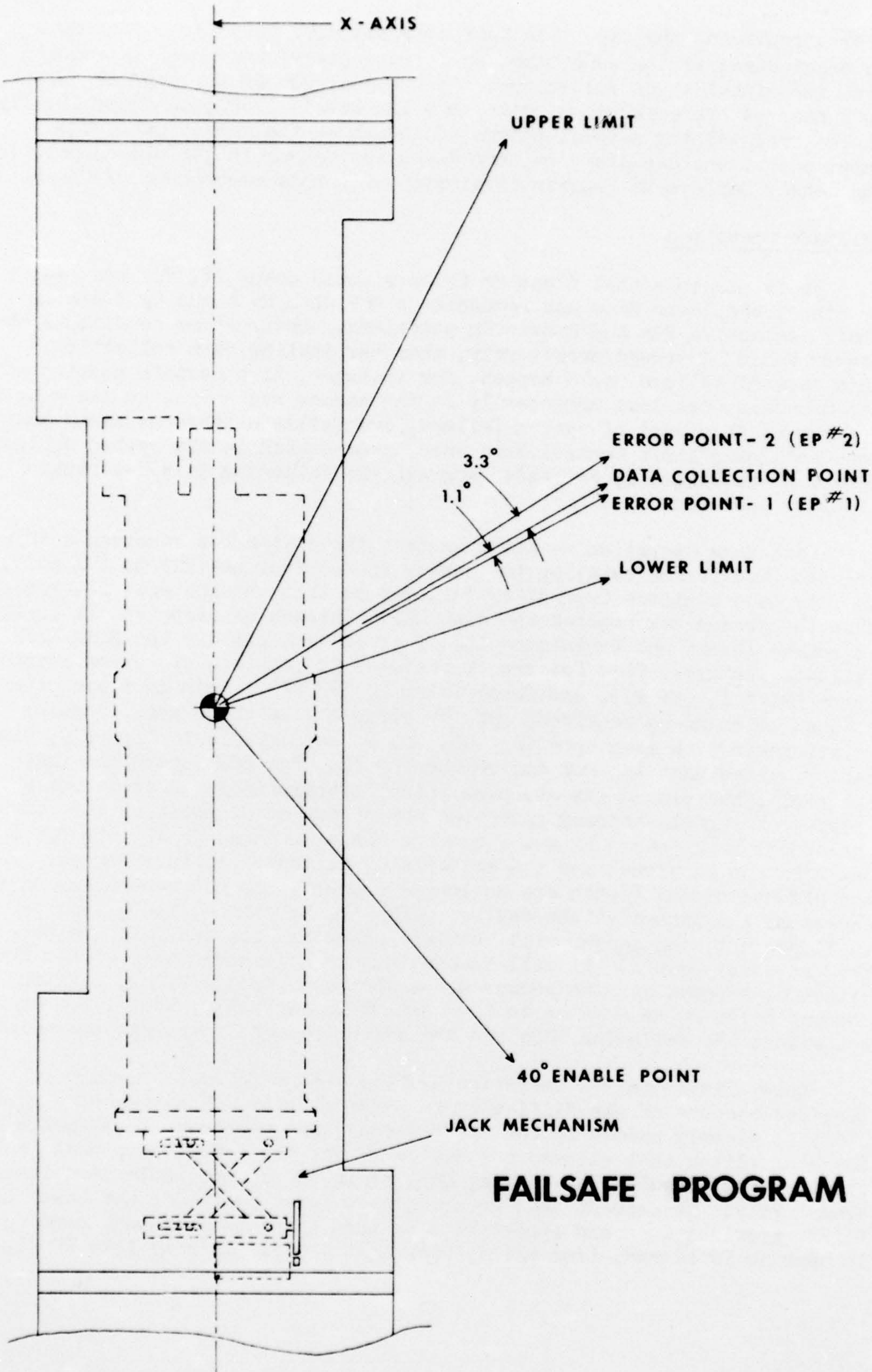

X - AXIS
UPPER LIMIT
ERROR POINT - 2 (EP #2)
3.3°
DATA COLLECTION POINT
1.1°
ERROR POINT - 1 (EP #1)
LOWER LIMIT
40° ENABLE POINT
JACK MECHANISM
FAILSAFE PROGRAM

Figure 9.

except that it remains fixed; it does not adjust its position each time a "Step" command is received.

It is assumed that any glitch capable of overriding these two failsafe features is probably more than a temporary problem and should be dealt with accordingly.

THE LOGIC CONTROL UNIT (LCU)

The LCU is the most complex component of the deployment system. As such, further explanation of its composition and operation is merited. It receives input information from three sources; they are the 40° Enable Switch, the Direction Monitor, and the SPE. Based on this information, the LCU decides upon and generates the correct combination of output signals which the system requires to perform any one of four system commands. These commands, "Logic Reset", "Deploy", "Step", and "Stow" are generated by the payload's programmer and the ACS. They determine what the control system must do and when to do it.

The following two segments, entitled "LCU Circuit Composition and Function", and "LCU Response to System Commands", elaborate on Figure 10, LCU Block Diagram. The first segment, as the title implies, describes the composition and function of each of the circuit blocks in this figure. The second segment illustrates the LCU's chronological response to each of the four system commands.

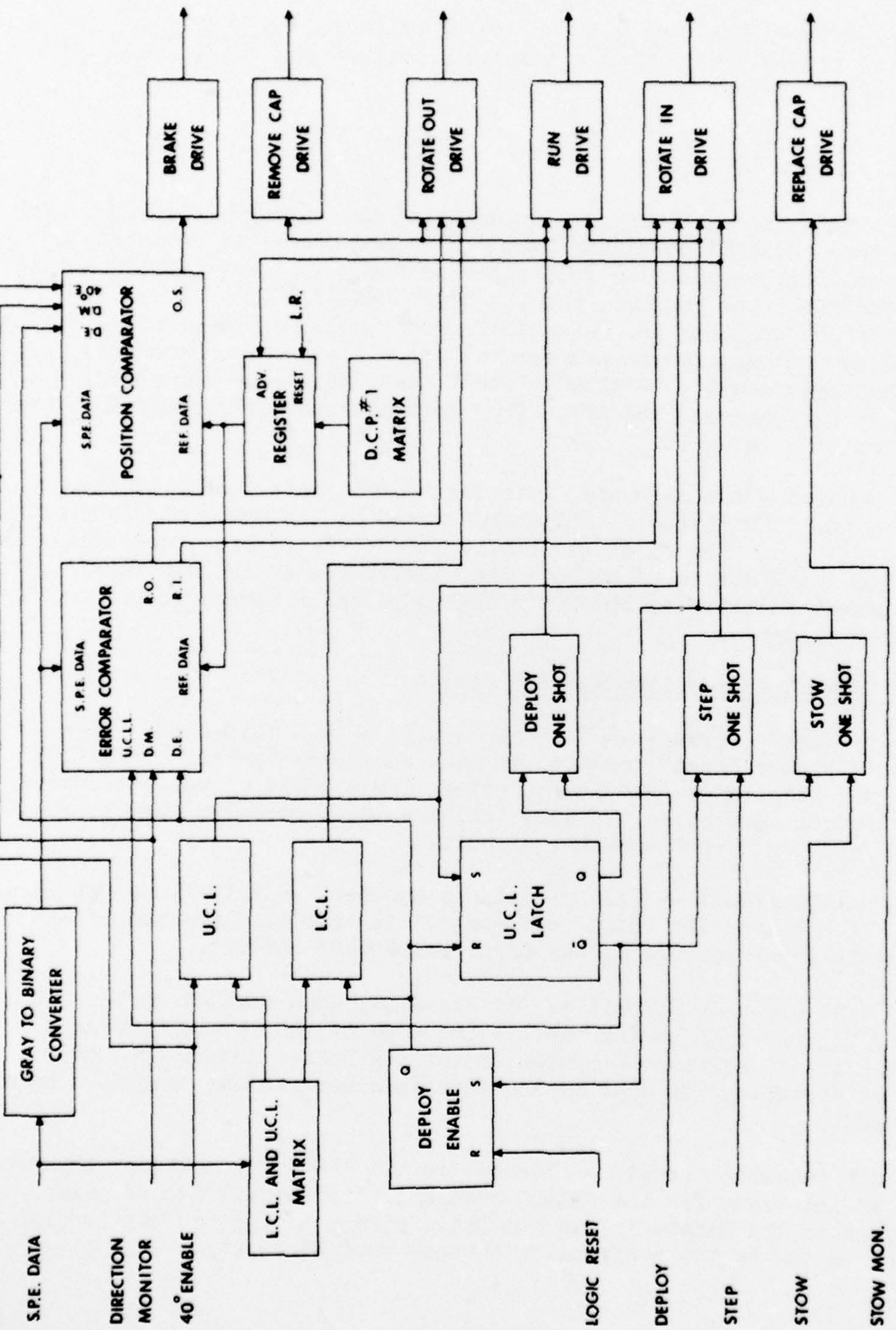
LCU Circuit Composition and Function

Deploy Enable Circuit -- This circuit is an R-S flip-flop. Upon receiving a "Logic Reset" command, it sets the Upper Control Limit (UCL) latch, Error Comparator, and Lower Control Limit (LCL) circuits to their proper starting condition. It also inhibits these circuits when it receives a signal from the "Stow" one-shot circuit.

UCL Latch Circuit -- This circuit is another R-S flip-flop. It is used to enable the "Step" and "Stow" one-shots. It also supplies one of the three enable inputs needed by the Error Comparator circuit.

"Deploy" One-Shot Circuit -- The one-shot, when enabled by the UCL latch circuit and upon seeing the leading edge of the "Deploy" command pulse, sends a 70 millisecond pulse to the Run Drive, Remove Cap, and Rotate Out circuits. It acts as the interface between the "Deploy" command and the LCU.

"Step" One-Shot Circuit -- Similar to the "Deploy" one-shot, this one acts as an interface for the "Step" command. Its 70 millisecond pulse output goes to the Rotate In and Run Drive circuits' inputs. It is also connected to the Register circuit's Advance control input.



LCU BLOCK DIAGRAM

Figure 10.

"Stow" One-Shot Circuit -- This one-shot is the LCU's interface for the "Stow" command. The output goes to the Rotate In Drive and Run Drive circuits. It also goes to the Set control input of the Deploy Enable circuit.

Gray to Binary Converter -- a pair of Quad, Two Input Exclusive OR gates provide eight gates, of which seven are used to convert the seven Most Significant Bits of the SPE Gray Code to the binary code format used by the LCU.

UCL Circuit -- A single 8 input NAND gate determines when the sensor is simultaneously beyond the 40° Enable Point and at the UCL point. Its output goes to the UCL Latch and Rotate In Drive circuits.

LCL Circuit -- Another single 8 input NAND gate is used to determine when the sensor is at the LCL point during the LCU's failsafe operating mode.

LCL and UCL Matrix -- This matrix is composed of two 14-pin DIP component carriers which provide a means of selecting, by hardwiring, the particular SPE data needed by the UCL and LCL circuits.

DCP #1 Matrix -- This matrix uses only one 14-pin DIP component carrier to select the angular position of the first data collection point, DCP #1. It is hardwired so that its output matches the SPE data for that point.

Register Circuit -- The Register circuit consists of two, 4 bit counters arranged as a 7 Bit Down Counter. It supplies the reference data that determines the angular position of the DCPs. The output feeds the Position Comparator and Error Comparator circuits.

Position Comparator Circuit -- This circuit employs a Dual 4 Bit Comparator, one 3 input NAND gate, one section of a Hex Inverter and one Dual Input one-shot. The circuit's main task is to recognize when the SPE data matches the reference data from the Register circuit. It also integrates the Deploy Enable, 40° Enable, and Motor Direction signals. Its output provides the input to the Brake Drive circuit.

Error Comparator Circuit -- This circuit is of significance only when the system is operating in the failsafe mode. It supplies the information which establishes the positions of FP #1 and FP #2. It is made up of one Dual 4 Bit comparator, two 3 input NAND gates, two 4 Bit True/Complement 0/1 Arithmetic Elements, and two 4 Bit Binary Adders. Its main inputs are from the SPE and Register circuits; it integrates these with inputs from the UCL Latch, Deploy Enable, and Direction Monitor circuits. It has two outputs; one goes to the Rotate Out Drive circuit and one to the Rotate In Drive circuit.

Drive Circuits -- The Replace Cap Drive, Brake Drive, and Remove Cap Drive circuits use single portions of a hex inverter as their input. The Rotate Out Drive and Run Drive use a 3 input NAND gate as their input, while the Rotate In Drive circuit uses a 4 input NAND gate. All six drive circuits

use an output transistor to supply power adequate to switch the control relays. It is these six output signals that make up the LCU's contribution to the control system.

LCU Response to System Commands

"Logic Reset" Command -- The first system command is the "Logic Reset". This is a pulse generated by the payload programmer at approximately T +52 seconds flight time. It is connected directly to the LCU's Register and Deploy Enable circuits. It resets the register by clearing any data in storage and enters the new data from the DCP #1 Matrix circuit.

When the Deploy Enable circuit receives this command, it is set to the Reset position. The Deploy Enable circuit has a single output which now simultaneously goes to four more circuits. Following each path, one place it goes to is the LCL circuit, supplying it with an enable input. Two more places are the Error Comparator and Position Comparator circuits where it removes an inhibit input. The fourth place it goes to is the UCL latch circuit. The UCL latch circuit responds by sending out two outputs labelled Q and $\overline{Q}$. The Q output goes to and enables the "Deploy" one-shot circuit. The $\overline{Q}$ output goes to three places: the "Step", and "Stow", one-shot circuits, and the Error Comparator circuit. It supplies an inhibit function at each.

This is the LCU's complete reaction to the "Logic Reset" command. No LCU output is generated at this time.

"Deploy" Command -- The second system command is the "Deploy". This pulse is normally generated by the ACS at T +110 seconds; however, it is backed up by the payload programmer at T +113 seconds. The only place it goes to in the LCU is the "Deploy" one-shot circuit. This circuit, previously enabled by the "Logic Reset" command, sends an output to three drive circuits. They are the Remove Cap, Rotate Out, and Run Drive circuits. The outputs from these three circuits are the LCU's control signals used to switch the relays needed for sensor deployment as previously described in the report segment Normal Operation.

During the sensor's deployment, the LCU receives certain pieces of information to which it must respond. The first of these is a change of status of the 40° Enable Switch. This input signal to the LCU enables the UCL circuit, and removes the second inhibit from the Position Comparator circuit. The SPF data is continuously monitored by the UCL circuit through the LCL and UCL Matrix circuit. When the SPF data matches the point determined by the matrix, the UCL circuit generates an output that goes to two places. At the Rotate In Drive circuit, it triggers an output which reverses the direction of sensor rotation. At the UCL latch circuit, several operations take place. The Q output from it inhibits the "Deploy" One-Shot, and its $\overline{Q}$ output enables both the "Step" and "Stow" One-Shot circuits; at the same time, it removes the second inhibit from the Error Comparator circuit.

When the sensor direction reverses, a signal received from the Direction Monitor removes the third or final inhibit from the Position Comparator and Error Comparator circuits. Both of these are now fully enabled and constantly monitor the data from the Gray to Binary Converter.

The Position Comparator looks for the point where SPE data matches data from the Register. When this happens, its output signal, conditioned by the Brake Drive circuit, stops the sensor at DCP #1. This terminates the influence of the "Deploy" Command.

"Step" Command -- This command, the third one received by the LCU, is a 350 millisecond pulse used to step the sensor from one DCP to the next. It is available only from the ACS and is repeated several times during a flight. The "Step" One-Shot circuit's output goes to the Run and Rotate In Drive circuits and starts the sensor rotating inward toward its next DCP. It also goes to the Register's Advance input.

The Register circuit's counter, up to this moment, stored the information received earlier from the DCP #1 Matrix. When it sees the one-shot output, it advances this information one count so that it now supplies a new reference, one that coincides with DCP #2. This reference is used by the Position Comparator as it monitors the SPE data, looking for a matching condition again. When it occurs, the LCU sends out the signals that stop the sensor, this time at DCP #2. Each time the LCU receives a "Step" command, this process is repeated.

Throughout this phase, the Error Comparator monitors the outputs of the SPE and the Register. Like the Position Comparator, it also looks for a matching condition of these two data sources. In its case, however, the data from the Register circuit is offset by the Error Comparator's circuit elements before an attempt to match it is made. The only time that a match is now possible is when the sensor, failing to stop at the designated DCP, travels 1.1° beyond to the EP #1. These same elements, with an input from the Direction Monitor, are used to generate the EP #2. The resulting action is as described in this report's segment entitled Failsafe Operation.

"Stow" Command -- A pulse from the ACS, backed up by the payload's programmer, terminates the stepping process and stows the sensor. This "Stow" command goes directly to the LCU's "Stow" One-Shot circuit. The one-shot's output then goes to the Run and Rotate In Drive circuits, thus starting the sensor rotating inward. It also supplies an inhibit signal to the two comparator and LCL circuits since any output from them would hinder the stowing process.

The sensor rotates inward until it reaches the Stow position, whereupon Sw 5 changes status, supplying an input to the Replace Cap Drive circuit. The output from this circuit is the last control signal generated by the LCU and serves to replace the sensor's cap.

CONCLUSION

This control system has proved to be quite versatile. The first seven projects used it as just described, changing only the angular position of the DCP #1 from project to project. Projects Nos. A05.391-1, -2, and -3 required reversing the stepping direction, starting DCP #1 at a low point and stepping outward instead of inward. The last project, Super Hi-Star, required the most modification. In this one, the Error Comparator circuit was used to scan the sensor 9.9° between the FP #1 and FP #2. It did so first at one position for calibration purposes, then at a second position to collect data. Additional circuitry was incorporated to smooth out the sensor's reversal of direction at each limit of the scan.

The system used in these eleven projects has proved so successful that its design concepts form the basis of new systems being developed for upcoming ZIP and ARIES/Autonetics projects at Wentworth Institute.

Mr. Christopher H. Hentschel, a former employee of Wentworth Institute, deserves special thanks in recognition of his contributions during the conceptual stage of this deployment system's Logic Control Unit.